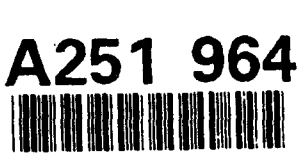

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Report on

US-Japan Seminar on Magnetic Multilayered Structures

Grant from the Office of Naval Research

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A US-Japan bilateral seminar on Magnetic Multilayered Structures took place in Kauai, Hawaii, from May 15 through 17 1992. There were twelve participants from Japan, and eleven from the United States. From the work presented at this seminar one finds that in the area of magnetic multilayered structures our interests complement those of the Japanese; while we both share an interest in the magnetoresistive properties, we focused on the interlayer coupling of these structures, while the Japanese were more interested in their magnetic and structural properties. The coupling of magnetic layers through nominally non-magnetic spacer layers was strongly represented by us at the seminar. The primary objectives of the US-Japan bilateral seminar were amply fulfilled: new information was presented, ideas were exchanged, and we got to know each other better.

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Report on

US-Japan Seminar on Magnetic Multilayered Structures

This bilateral seminar took place at the Stouffer Waiohai Beach Resort on the island of Kauai, Hawaii, from May 15 through 17 1992. There were twelve participants from Japan, and eleven from the United States. In addition, there was one observer-participant from Canada (Bret Heinrich, Simon Fraser University), and two observers from the United States (Kristl Hathaway, Office of Naval Research and Randy Hood, University of California at Berkeley). The majority of the funding for the United States came from the National Science Foundation (nine participants); the Office of Naval Research funded two additional US participants and the Faculty of Arts and Science of New York University provided funds for the Canadian participant, and for incidental items. The Japan Society for the Promotion of Science provided funds for the other side.

At the outset it must be stated that the choice of setting for the bilateral seminar was superb. The Stouffer Hotel is extraordinary: we were provided with a large meeting room, well lit, and with an excellent overhead projector. The coffee service was extremely well done, and the staff at the hotel was very accomodating in every aspect of our needs for the seminar. I highly recommend the Stouffer Waiohai in Kauai for future US-Japan meetings. Each participant was alloted 45 minutes for their presentation and discussion. By and large, the presentations by the Japanese were fluent and they communicated effectively. The extended abstracts of the presentations have been gathered together into a booklet; this represents the written record of the seminar.

From the work presented at this seminar one finds that in the area of magnetic multilayered structures our interests complement those of the Japanese; while we both share an interest in the magnetoresistive properties, we focused on the interlayer coupling of these

structures, while the Japanese were more interested in their magnetic and structural properties. For example, they reported their work on using multilayering to obtain "soft" magnetic materials (low coercivity and large magnetic moments), the change in mechanical properties under high pressure (up to 8GPa), and polarized neutron studies to determine the magnetic structures existing in superlattice. While there is similar work done on these aspects in the United States, our representation at this seminar was limited to a study of the structural influences on the magnetic anisotropy of cobalt-palladium superlattices (this structure has perpendicular anisotropy and is a strong candidate for "vertical" recording). One noteworthy presentation was that on an NMR study of magnetic multilayers which is able to provide highly useful information on the magnetic neighbors to the nucleus undergoing resonance. This technique is used to characterize the interfacial region between layers and has been pursued in France and to a lesser degree here in the United States.

The coupling of magnetic layers through nominally non-magnetic spacer layers was strongly represented by us at the seminar. There was a report from Sendai (Takanashi) of an experimental study on magnetic multilayers, e.g., iron-gadolimium, whose interpretation relies heavily on theoretical analyses done years ago by Bob Camley and updated by him at this seminar.

The main themes emerging from this joint seminar were:

1) For some spacer layer elements, e.g., silver and gold, whether or not one obtains oscillatory antiferromagnetic-ferromagnetic coupling depends crucially on the method of preparation.

2) If oscillatory coupling is seen, for such elements as copper, there is no consensus on whether the oscillations are described by one or two different wavelengths. For other, e.g., chromium, two different wavelengths have been positively identified.

3) While it is not possible to rely on perturbative calculations for the strength of interlayer coupling, a study has shown that they do reproduce the period of the oscillations found in non-perturbative model calculations, at least for one-dimensional systems.

4) The explanation for biquadratic (90) *alignment* between adjacent magnetic layers is unclear. The temperature dependance observed for this coupling casts some doubt on the current explanation (a sort of frustration phenomenon).

5) While "giant" (unusually large) magnetoresistance has been observed for currents in the plane of the layers, there are measurements now for currents *perpendicular* to the layers. If the spacer layers between the magnetic ones are insulators; e.g., aluminum oxide, it's not difficult to maintain a reasonable voltage drop across such a junction, but the magnetoresistance observed to date is not large. When the spacer layer is metallic the drop in voltage is so small as to require a superconducting quantum interference measurement to detect it; this necessitates measurements at liquid helium temperatures. However for metallic spacer layers the magnetoresistive effect can be large, in fact invariably larger than it is in the conventional in-plane geometry.

6) The role of scattering at interfaces was stressed as the dominant mechanism for magnetoresistance. In a series of experiments it was shown that the magnetoresistance was doubled when spin-dependent scatterers were placed at the interface between layers as compared to when they were inside the bulk of a layer.

7) There are quite a large number of parameters which control magnetoresistance in multilayered structures; up to *twenty*. These describe the spin-dependent and independent scattering in the layers and at the interfaces, and the differences in the potentials between layers. To have a manageable theory, one must focus on the primary cause in order to reduce this number. Spin-dependent scattering is without question the single most important parameter to control the magnetoresistance.

8) While the mean free path of conduction electrons is a critical parameter for the magnetoresistance for current in the plane of the layers this is *not* the case for currents perpendicular to the layers.

9) While it has been established that the perpendicular interface anisotropy is independent of the epitaxial orientation, e.g., (100), (110) or (111), for cobalt-palladium multilayers, this result will *probably* not hold for multilayers with iron or nickel. For these the magnetic moments at the interface vary with orientation, and therefore interface anisotropy should vary with orientation.

10) In rare-earth superlattices it has been firmly established that the RKKY interaction explains the interlayer coulping in these structures. This coulping is sensitive to the topology of the Fermi surface and the coupling has been found to accurately reflect the symmetry of

this surface, i.e., for yttrium spacer layers one finds coupling of successive magnetic layers up to 150A along the c-axis, but only up to 20A along in-plane directions.

11) Finally, the spin polarization of conduction electrons in paramagnetic spacer layers due to the magnetic layers has been observed in two systems. Yasuoka reported on this for copper spacer layers from his NMR data on the copper Knight shift; Pierce presented evidence for this spin polarization in a chromium wedge-like film on top of an iron whisker from images obtained by using scanning electron microscopy with polarization analysis.

The primary objectives of the US-Japan bilateral seminar were amply fulfilled: new information was presented, ideas were exchanged, we got to know each other better, and many of us got to a first name basis. One point of self-criticism is that not enough time was left for more informal discussions; this would have been possible if the seminar were extended to a fourth day. Financial constraints did limit us to three days. All said, it was an extremely constructive exchange of views and ideas; nearly everyone found the setting for this seminar an ideal location.